# VCE CHEMISTRY
# CAT 3 1992

# "ANALYSIS AND EVALUATION"

# DETAILED SUGGESTED SOLUTIONS

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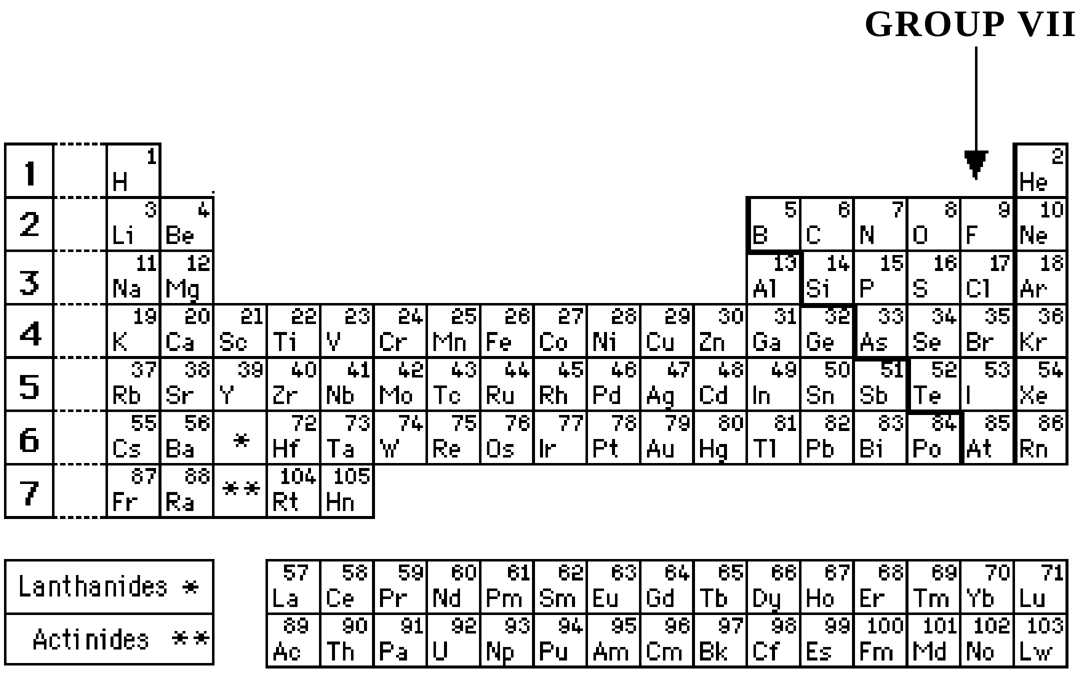
## Section A

### Question 1

**(Please note that only nine lines were allowed to students in answering question 1b. The information provided here far exceeds what would be expected of students to gain full marks on this question.)**

**a.** In the Periodic Table shown below, the elements shown are those in Group VII (Group 17 counting from left to right). This is the group of five elements known as the halogens with the general electronic configuration $ns^2np^5$.




**b i**

**PHYSICAL PROPERTIES OF THE ELEMENTS**

Four elements from Group VII are (in order of increasing atomic number)
fluorine (F), chlorine (Cl), bromine (Br) and iodine (I). At room temperature and pressure, fluorine is a yellow gas, chlorine is a greenish-yellow gas, bromine is a dark red liquid and iodine is a black, shiny solid. All exist as diatomic molecules.
As the atomic number increases,
(1) the atoms and molecules become larger.
(2) the melting and boiling temperatures of the elements increase.
(3) the electronegativities decrease.
(4) the relative molecular masses increase.
(5) the densities increase.
(6) the bond lengths in the diatomic molecules increase.
(7) the heats of vaporisation increase ($kJmol^{-1}$)
(8) the bond dissociation energies decrease from $Cl_2$ to $I_2$ ($F_2$ is lower than expected).
(9) the $E^o$ values decrease.

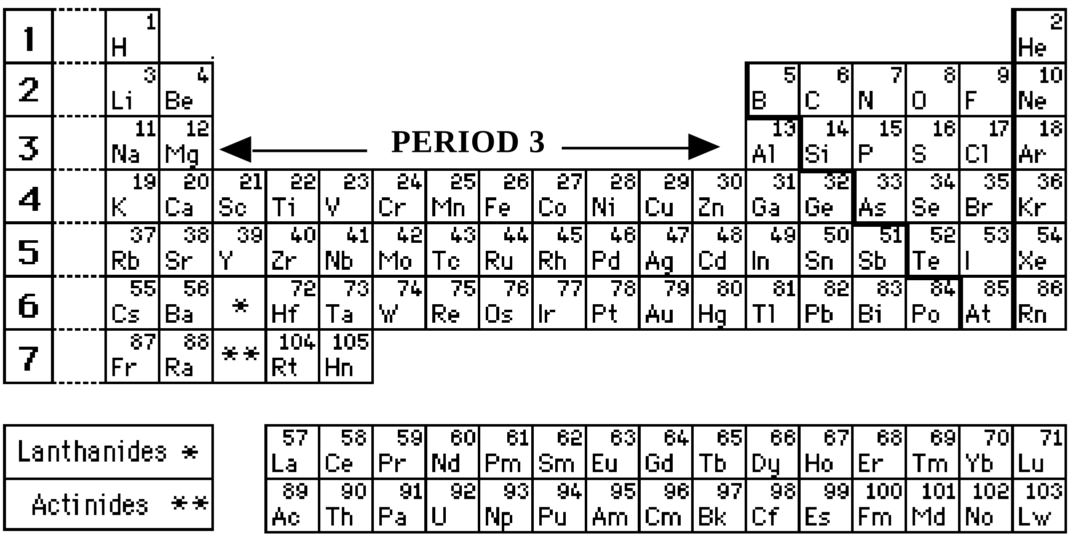
## PHYSICAL PROPERTIES OF THE HYDRIDES

The hydrides of these elements are hydrogen fluoride (HF), hydrogen chloride (HCl), hydrogen bromide (HBr) and hydrogen iodide (HI). As the atomic number increases,
(1) the relative molecular masses increase.
(2) the boiling temperatures increase from HCl to HI but the boiling temperature of HF is unexpectedly high.
(3) the melting temperatures increase from HCl to HI but the melting temperature of HF is unexpectedly high.
(4) the bond dissociation energies decrease.
(5) the solubility in water increases from HCl to HI. (HF is miscible).
(6) the acidity constant increases.

## OXIDATION-REDUCTION PROPERTIES OF THE ELEMENTS

Of all the elements, fluorine is the strongest known oxidant. It has the most positive $E^o$ value at +2.87V for the half-reaction $F_2(g) + 2e^- = 2F^-(g)$. The $E^o$ values decrease progressively down the group. Hence, $F_2$ will oxidise $Cl^-$, $Br^-$ and $I^-$ to $Cl_2$, $Br_2$ and $I_2$ respectively. $Cl_2$ will oxidise both $Br^-$ and $I^-$ but not $F^-$. $Br_2$ will oxidise $I^-$ only.

**a.** In the Periodic Table shown below, the elements shown are those in Period 3
(the third row of elements). These are the eight elements with their outershell electrons in the third energy level from $3s^1$ to $3s^23p^6$.




**b ii**

## FORMULAS OF THE HYDRIDES

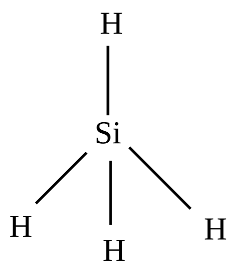
The formulas of the hydrides are NaH, $MgH_2$, $AlH_3$, $SiH_4$, $PH_3$, $H_2S$, HCl. As the atomic number of the element increases, the number of hydrogens bonded increases to a maximum of 4 and then decreases. The change in the number of hydrogens reflects the tendency of the atoms to gain the outershell configuration $3s^23p^6$.

## ACID-BASE PROPERTIES OF THE HYDRIDES

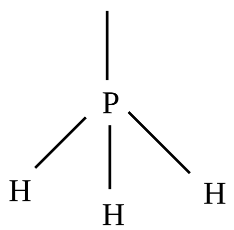
NaH, $MgH_2$, $AlH_3$ are strongly basic hydrides since the hydride ion $H^-$ reacts violently with water according to the equation: $H^-(aq) + H_2O \ = \ OH^-(aq) + H_2(g)$.
$SiH_4$ is neutral since it does not react with water. $PH_3$ is weakly basic according to the equation:
$PH_3(g) + H_2O(l) \ = \ PH_4^+(aq) + OH^-(aq)$. $H_2S$ is weakly acidic while HCl is strongly acidic according to the respective equations:
$H_2S(g) + H_2O(l) \ = \ H_3O^+(aq) + HS^-(aq)$
and $HCl(g) + H_2O(l) \ = \ H_3O^+(aq) + Cl^-(aq)$.
Hence, the hydrides change from basic to neutral to acidic as the atomic number increases across period three.

## STRUCTURE AND BONDING IN THE ELEMENTS

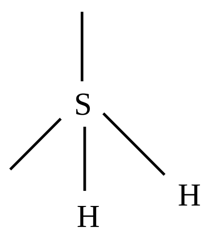
NaH and $MgH_2$ form ionic lattices containing the $H^-$ ion. $AlH_3$ has bonds which are partly covalent. $SiH_4$, $PH_3$, $H_2S$ and HCl are molecular compounds with structures based on a tetrahedron of electron pairs as shown below. Hence, as the atomic number increases, the structure changes from three dimensional lattice to discrete molecules and the bonding changes from ionic to covalent.



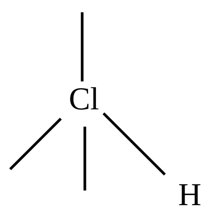
Silane



Phosphine

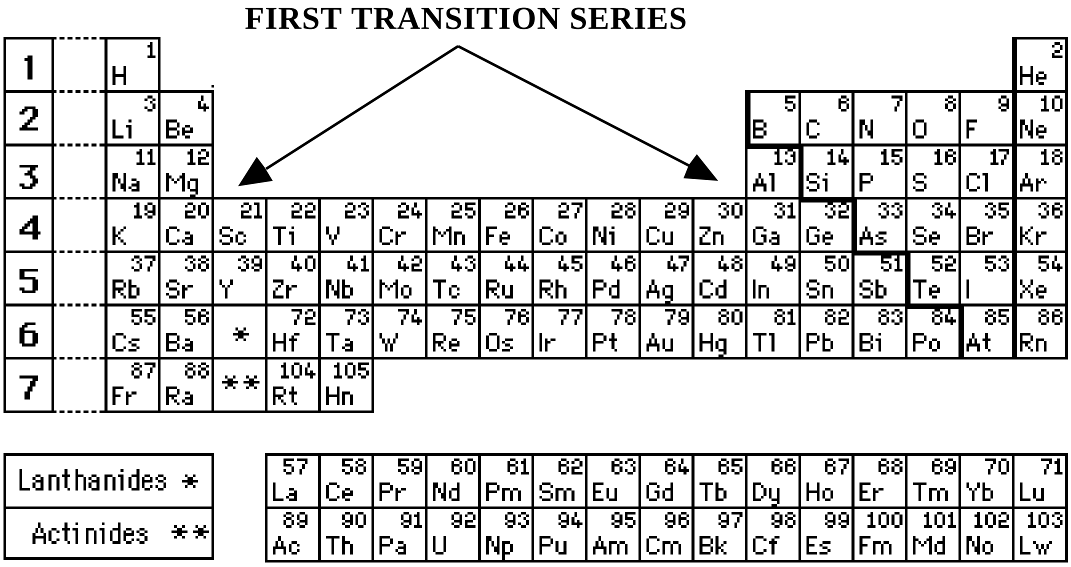


Hydrogen sulfide



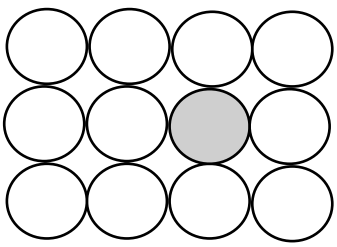
Hydrogen chloride

**a.** In the Periodic Table shown below, the elements shown are those in the first transition series. These elements correspond to the gradual filling of the 3d subshell from $3d^1$ to $3d^{10}$.

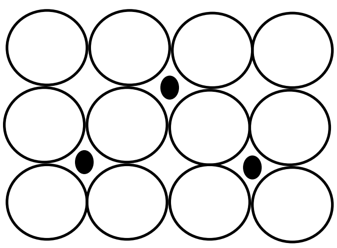



**b iii STRUCTURE AND BONDING IN THE ELEMENTS (SOLIDS)**

There is strong metallic bonding in the transition metals. This is shown by the hardness, high melting temperatures and electrical conductivity of these elements. The metal ions form a three dimensional lattice structure with the outershell electrons free to drift through the metal when an electric potential is applied. The structure and bonding of the transition elements are closely related to the electronic configuration of the elements in which the 3d subshell is being filled as the atomic number increases from 21 to 30. Usually, the transition metals form alloys (mixtures of elements with carefully controlled compositions) for use in real situations. These alloys can be substitutional solid solutions in which different but chemically similar atoms of approximately the same size are mixed in the crystal lattice. The alloys can also be interstitial solid solutions in which smaller atoms are packed randomly into the spaces between the regular array of metal atoms. These alloy structures are shown below.



Substitutional solid solution



Interstitial solid solution

## OXIDATION-REDUCTION PROPERTIES OF THE ELEMENTS

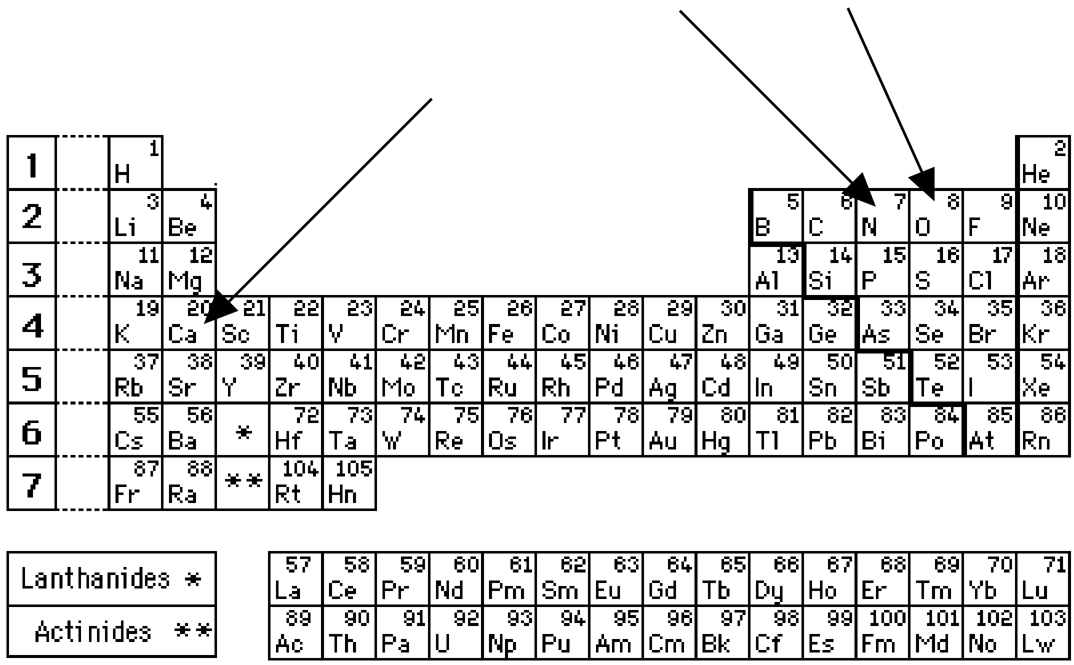
The transition elements show variable oxidation numbers because they are able to lose either the 4s or 3d electrons because these electrons have similar energies. Some of these oxidation states are: $Sc^{+}$ (+1), $Mn^{2+}$ (+2), $Cr^{3+}$ (+3), $MnO_2$ (+4), $V_2O_5$ (+5), $CrO_3$ (+6), $KMnO_4$ (+7). Since the transition **metals** are losing electrons to achieve these positive oxidation states, they are acting as reductants in chemical reactions. Of course, many of their compounds containing the transition element in a high oxidation state will act as oxidants. These variable oxidation states are important in the execution of some industrial and biological reactions by catalysis.

**Question 1**

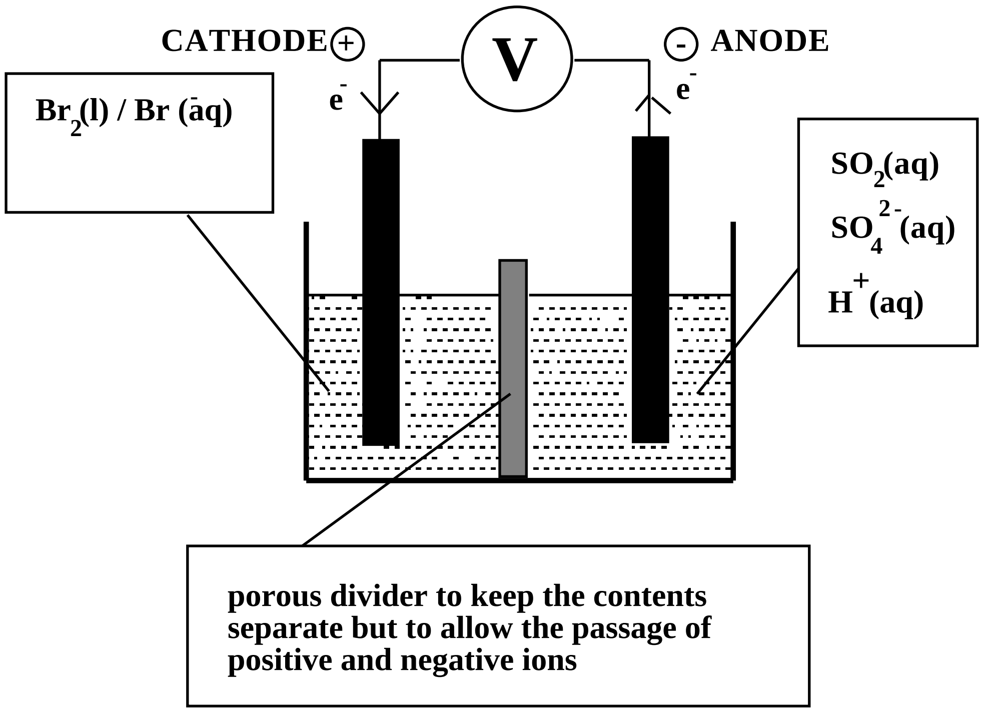
**c. i.** The electronic configuration of nitrogen, N (atomic number = 7) is $1s^22s^22p^3$.
The electronic configuration of oxygen, O (atomic number = 8) is $1s^22s^22p^4$.

**c. ii.** The positions of N and O in the Periodic Table are shown below.

**d.** This atom has 20 electrons and, therefore, must have 20 protons in its nucleus. It has an atomic number of 20. The element is calcium, Ca, and its position in the Periodic Table is shown below.



**Question 2**
**a.**




**b.** When the cell is **discharging:**
At the cathode, reduction occurs: $Br_2(l) + 2e^- = 2Br^-(aq)$.
At the anode, oxidation occurs: $SO_2(aq) + 2H_2O(l) = SO_4^{2-}(aq) + 4H^+(aq) + 2e^-$

**c.** The electrode materials must be inert so that they do not react with the contents of the half-cells. They must be good electrical conductors and, if possible, should catalyse the reactions in the half-cells.

**d.** A cell that had been discharged, could be recharged by using a potential greater than 0.89 V. The **negative** terminal (source of electrons) of the EXTERNAL power source must be connected to the electrode immersed in the $SO_2(aq)/SO_4^{2-}(aq)$ half-cell so that reduction will occur while the **positive** terminal of the EXTERNAL power source must be connected to the electrode immersed in the $Br_2(l)/Br^-(aq)$ half-cell so that oxidation will occur.

**e.** When the cell was being **recharged**, the half-cell reactions would be

$2Br^-(aq) = Br_2(l) + 2e^-$ and $SO_4^{2-}(aq) + 4H^+(aq) + 2e^- = SO_2(aq) + 2H_2O(l)$

The OVERALL REACTION would be:
$2Br^-(aq) + SO_4^{2-}(aq) + 4H^+(aq) = Br_2(l) + SO_2(aq) + 2H_2O(l)$

**Question 3**

**a.** The calibration factor of the calorimeter is the energy required to raise the temperature of the calorimeter and its contents by $1^oC$. In this case, 27500 J is required to raise the temperature by $(28.053 - 27.432) = 0.621^oC$.

Hence, the calorimeter constant = K = $\frac{27500}{0.621}$ = 44283.4 J/$^o$C. = 44.3 kJ/$^o$C. **ANS**

**b.** Energy content ('TUFFBRAN') $= \frac{K \times \Delta T}{10} = \frac{44283 \times (27.432 - 25.238)}{10}$

= 9716 J/g **ANS**

Energy content ('KORNYFLAKES') = $\frac{K \times \Delta T}{10} = \frac{44283 \times (25.254 - 23.222)}{10}$

= 8998 J/g **ANS**

**c.** In the calorimeter, the food is burnt completely. If the same thing happened in the body, then 'TUFFBRAN' would be more fattening than 'KORNYFLAKES' since it provides a larger number of joule per gram. However, this assumes that both foods are absorbed by the body in exactly the same way and that after absorption, the components are oxidised in exactly the same way. Neither of these assumptions has any evidence to support them. More information is required.

**d.** Experiments would have to be done on both foods to determine:

(1) the amount of each food absorbed by the body after digestion.

(2) the composition of each food in terms of carbohydrate, fat, protein and insoluble fibre.

**Question 4**

**a.** At the positive electrode, oxygen gas is produced by oxidation of the water. Hence, this is the ANODE.

The equation for the half-reaction is: $2H_2O(l) = O_2(g) + 4H^+(aq) + 4e^-$

At the negative electrode, copper metal is deposited by reduction of the copper ions. Hence, this is the CATHODE.

The equation for the half-reaction is: $Cu^{2+}(aq) + 2e^- = Cu(s)$

**b.** (1) The dissociation of copper sulfate into positive copper ions and negative sulfate ions is **not** caused the passage of electricity. The polar water molecules provide the energy to disrupt the ionic lattice structure of copper sulfate.

(2) Water is a covalent molecule. The passage of electricity does not cause it to ionise to any great extent. In fact, the water molecules give up electrons to produce hydrogen ions and **oxygen gas.**

(3) Sulfuric acid remains largely ionised in aqueous solution.

**Question 5**
**a.** A **mass spectrometer** could be used to determine that only one element was present and that only one isotope of this element was in the sample.

**b.** The mass spectrometer identifies an isotope on the basis of its mass to charge ratio. If the sample contains only one element with a single proton (hydrogen) and only one isotope (tritium), then the mass spectrometer will show only one peak in its output. If there is more than one peak, then the claim is false!

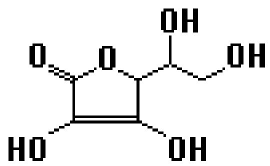
**Question 6**
**(There are a large number of possible correct answers to this question)**

A common food additive is Vitamin C (Ascorbic Acid)

a. Ascorbic acid is added to foods such as margarine, beer and chewing gum.

b. The purpose of ascorbic acid is to prevent substances from reacting with atmospheric oxygen and thereby becoming sour or rancid.

c. Ascorbic acid is classified as an antioxidant. It has the chemical structure




Vitamin C
(ascorbic acid)

**Question 7**

**STAGE A**
The carbon dioxide in the atmosphere is used by green plants in photosynthesis to produce glucose and oxygen gas according to the overall equation:
$6CO_2(g) + 6H_2O$ (chlorophyll, sunlight) $= C_6H_{12}O_6(aq) + 6O_2(g)$

**STAGE B**
When green plants die and are subjected to heat and pressure over a long period of time, coal and oil are produced.
The coal and oil consist mainly of hydrocarbons ($C_xH_y$)

**STAGE C**
Coal is mined and used in the production of electric power. In the case of brown coal, a large amount of water must first be removed. Oil is pumped from its underground reservoirs and refined to produce a wide variety of useful products.

**STAGE D**
When coal or oil are burnt completely in oxygen, carbon dioxide and water are produced according to the equation: $C_xH_y(s)(l) + (x + \frac{y}{4})O_2(g) = xCO_2(g) + \frac{y}{2}H_2O(g)$. If incomplete combustion takes place, then carbon monoxide (CO) is also produced. Other constituents in the coal and oil such as sulfur will produce other gases (such as sulfur dioxide) during combustion.
In respiration, glucose is burnt in oxygen to produce carbon dioxide and water according to the overall equation:
$C_6H_{12}O_6(aq) + 6O_2(g) = 6CO_2(g) + 6H_2O$.

**STAGE E**
Plants also respire to produce carbon dioxide in the same way as animals according to the overall equation: $C_6H_{12}O_6(aq) + 6O_2(g) = 6CO_2(g) + 6H_2O$.

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